Large-Eddy Simulations of Tropical Convective Systems, the Boundary Layer, and Upper Ocean Coupling

Eric D. Skyllingstad

College of Oceanic and Atmospheric Sciences, Oregon State University

104 COAS Admin. Bldg., Corvallis, OR 97331

Phone: (541) 737-5697   Fax: (541) 737-2540   Email: skylling@coas.oregonstate.edu

Simon de Szoeke

College of Oceanic and Atmospheric Sciences, Oregon State University

104 COAS Admin. Bldg., Corvallis, OR 97331

Phone: (541) 737-8391   Fax: (541) 737-2064   Email: sdeszoek@coas.oregonstate.edu

LONG-TERM GOAL

Improve operational numerical weather prediction (NWP) models to more accurately simulate the interaction of tropical deep convection and atmospheric and oceanic boundary layers.

OBJECTIVES

Investigate tropical convection and upper ocean circulations on scales from 100 m to 200 km. Elucidate specifically how the ocean mixed layer responds to forcing from atmospheric convection such as wind and precipitation, and thus how surface fluxes depend on the history of convective events. Perform high-resolution coupled atmosphere-ocean numerical model simulations, whose fidelity is a benchmark for operational models and parameterizations. Insights gained from these simulations will be used to improve parameterizations used in operational scale models, and to refine hypotheses in collaboration with investigators working on observational field studies in the Indian and West Pacific Oceans.

APPROACH

Intraseasonal variability in the tropics is dominated by the Madden-Julian Oscillation (MJO), which generates large-scale variability in the structure and organization of deep convective cloud systems. MJO events consist of multiple scales of convective activity, from single kilometer-sized cells to circulations encompassing half of the tropical Pacific. Key factors for tropical convection include sea-surface evaporation and large-scale atmospheric moisture convergence, which both depend on sea-surface temperature and wind speed. Most numerical models do not resolve turbulent and convective scales, nor do they simulate the MJO accurately. We plan to investigate how convection during the active phase of MJO affects and interacts with the ocean mixed layer. We will perform large eddy simulation (LES) of organized convective systems, which resolve boundary layer eddy scales to mesoscale convective towers. These numerical simulations will reveal how atmospheric convection

Report Documentation Page

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **Large-Eddy Simulations of Tropical Convective Systems, the Boundary Layer, and Upper Ocean Coupling**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Oregon State University,College of Oceanic and Atmospheric Sciences,104 COAS Admin Bldg,Corvallis,OR,97331-5503**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

alters air-sea fluxes and the ocean boundary layer, and will refine hypotheses on coupling between the ocean and atmospheric boundary layer during MJO events, to be tested during the field campaign. Processes on these scales are gaining importance in operational NWP models as the realism of convection increases along with model resolution.

WORK COMPLETED

Research during the first (partial) year of this project has focused on defining the range of input parameters for conducting LES experiments in the Indian Ocean region. We have concentrated our efforts on data collected during the MISMO (*Mirai* **I**ndian Ocean Cruise for the **S**tudy of the **MJO**-convection **O**nset) experiment performed by the Japan Agency for Marine-Earth Sciences and Technology (JAMSTEC). These data include extensive radiosonde data and Doppler radar imagery, as well as a suite of oceanographic measurements, which were collected during the onset stage of an MJO event. Here we present a preliminary assessment of the radiosonde data as an indicator of convective intensity, along with rudimentary LES results using these data as initial conditions.

RESULTS

Intraseasonal evaporation anomalies over the Indian and West Pacific Oceans

It is uncertain whether surface heat fluxes are an essential component of tropical intraseasonal variability in the atmosphere over the Indian Ocean. If the ocean-atmosphere interaction is important, then surface fluxes must be responsible for communicating this variability to the lower atmosphere. Sobel et al. (2008) argue that ocean surface heat fluxes are important, showing larger intraseasonal variability of rainfall over ocean than over land, despite larger mean rainfall over land in the Maritime Continent. Other theories suggest moist enthalpy and gross moist stability of the atmospheric column control atmospheric convection. Evaporation is the largest term in the surface heat budget and influences the moist enthalpy more than any other surface flux.
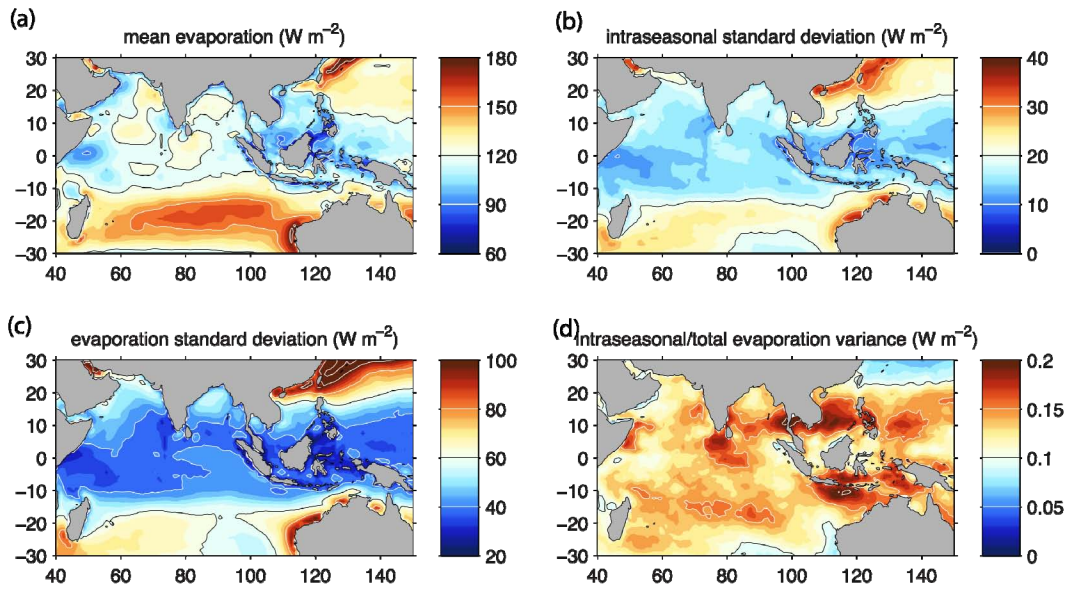

Figure 1. Evaporation in the Indian and West Pacific Oceans from OAFlux.
(a) Mean climatological evaporation. (b) 30-90 day filtered

We computed the evaporation mean, variability, and intraseasonal variability from daily WHOI OAFlux evaporation product (Yu and Weller 2007). Figure 1 shows the regional patterns of evaporation. This product shows it is around 120 W/m^2 in the Indian Ocean; and less in the Maritime Continent seas and Western Pacific. There's a narrow meridional feature along the Maldives and Chagos Islands. Total standard deviation (fig. 1c) of the evaporation is about 40 W/m^2 in the tropical Indian and West Pacific Oceans. It increases abruptly at ±15-20 latitude, and it's more and where influenced by continents, but less near the islands of the Maritime Continent.

We filtered the evaporation with a 30-90 day filter in Fig. 1b. The intraseasonal standard deviation of evaporation (top right) follows the same pattern as the total standard deviation, but it increases more gradually from ±10-20 latitude. The intraseasonal fraction of variance (Fig. 1d) is about 0.13 in the Indian and West Pacific Ocean, and larger (approaching 0.2) in the ±10 degree latitude range of the Maritime Continent. From present analysis we suppose that the modest evaporation anomalies could influence the formation of intraseasonal oscillations in the Indian Ocean, but seem unlikely to be a primary driver without additional atmospheric feedbacks to the marine boundary layer moist enthalpy budget.
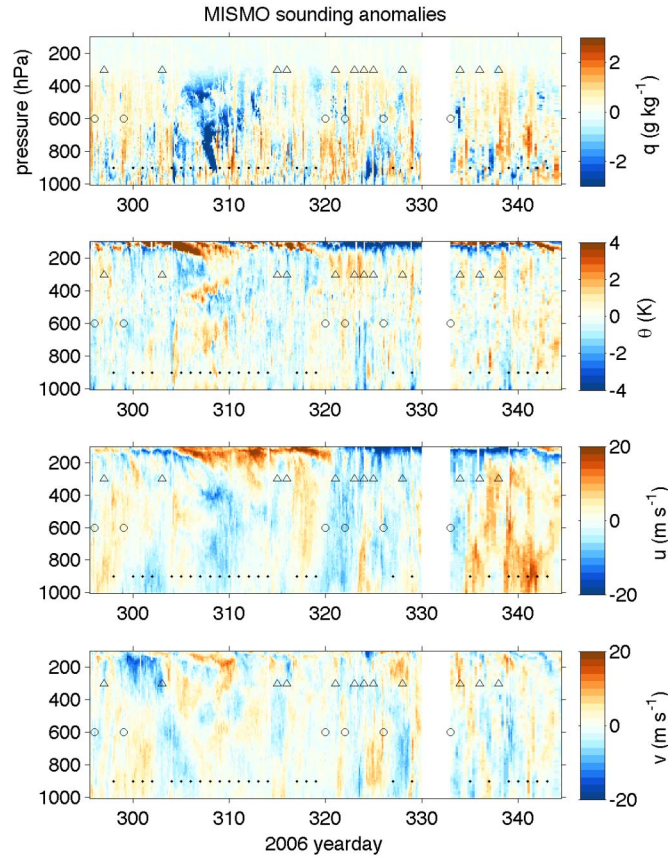

Figure 2. Time-height anomalies of specific humidity q, potential temperature θ, zonal u and meridional v wind. Most of the variability is due to an anomalously dry week in days 305-312. There are ~±1 K diurnal potential temperature anomalies. Westerly anomalies pick up after day 335. There's suggestion of a 10-day cycle in zonal winds. Meridional wind anomalies are smaller with shorter time scales.

Variability in the MISMO soundings

In 2006 the JAMSTEC Research Vessel *Mirai* traveled to the Indian Ocean for MISMO, scanning the sky with precipitation radar and profiling the atmosphere with over 300 rawinsondes (Yoneyama et al. 2008). MISMO provides useful data for modeling and hypothesis development in preparation for the CINDY/DYNAMO and ONR DRI experiments planned in the Indian Ocean in 2011.

We grouped soundings by their convective population, as diagnosed from MIRAI radar images. Black symbols in Fig. 2 show the convective scale as diagnosed from inspection of radar at 18 UTC. Black dots (aligned at 900 hPa) have 'popcorn' convection at 18 UTC with horizontal scales less than 100 km. Circles (600 hPa) had convection with scales ~100 km, or indeterminate scales. Triangles (300 hPa) had convection clusters with scales significantly greater than 100 km. Convection organized on scales larger than 100 km does not seem to correspond to obvious differences in the soundings.
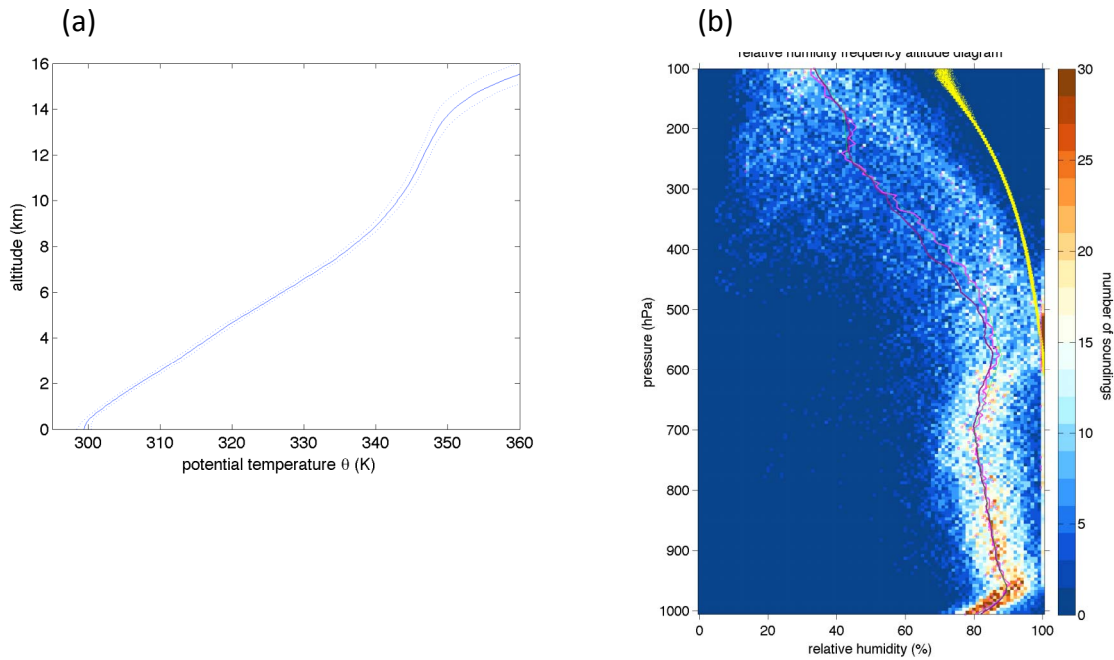
(a) (b)

Figure 3. (a) Potential temperature profile and standard deviation. Standard deviation of potential temperature is 0.5 K in the free troposphere. (b) Altitude-resolved histogram of the relative humidity (RH) measured by all MISMO soundings. RH of 100% indicates the radiosonde rose through a cloud. The purple and magenta lines show mean and median relative humidity, and the yellow lines show RH over liquid water for water vapor saturation over ice.

Figure 3a shows the potential temperature mean and standard deviation. The standard deviation is <1 K throughout the troposphere, and mostly <0.5 K. Relative humidity varies much more. The time-height anomaly section above indicates time dependence, but the humidity is not normally distributed—with a separate mode of 100% when the sounding rose through a cloud, rather than the more common clear environment. Figure 3b shows the histogram of relative humidity *RH* for each pressure level. Purple and magenta lines are average *RH* profiles, squares indicate the mode of the distribution. *RH* increases from ~80% at the surface to 950 hPa. The sondes often rose through clouds with saturated humidity (*RH*=100%). Between 600-500 hPa, the mode of the distribution is at saturation, though there are less-

4

frequent subsaturated soundings. Above 500 hPa *RH* (over liquid) decreases partly because of vapor saturation over ice at sub-freezing temperatures ($e_{s,ice}<e_{s,liquid}$). The yellow line shows the relative humidity over liquid of water vapor saturated over ice at the sounding temperature. The mode of the *RH* distribution is yet lower than saturation over ice, and the distribution is negatively skewed with some extremely dry soundings.

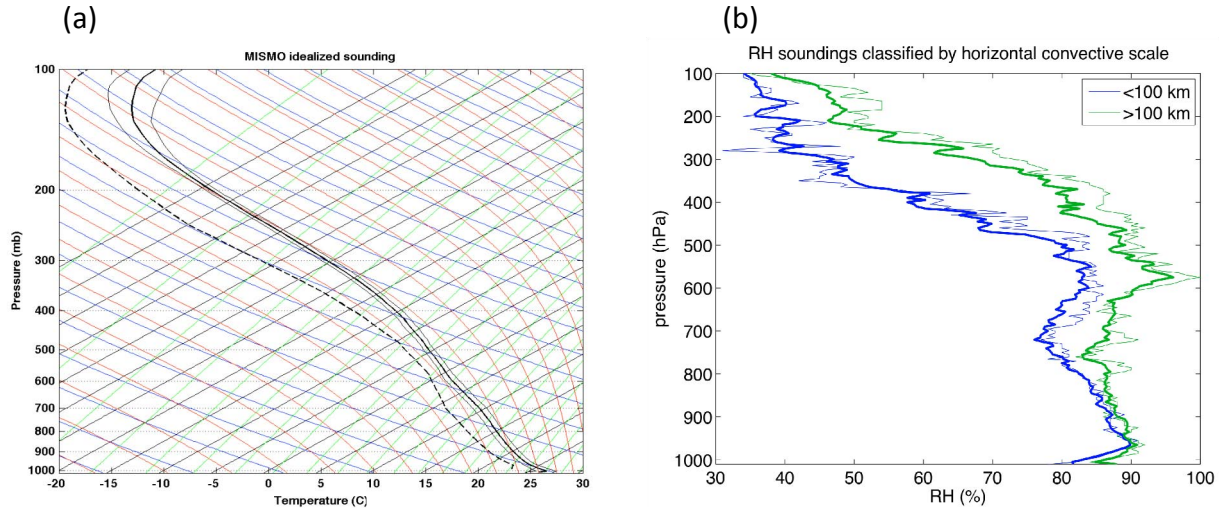(a)   (b)

Figure 4. (a) Idealized sounding temperature (black solid) and dew point temperature (dashed) on a log-p skew-T diagram. (b) Relative humidity differences for horizontal convective scales less than 100 km (blue) and greater than 100 km (green). Thick lines are composite means, thin lines are composite medians.

We used the distribution of the soundings to construct an idealized sounding for model studies. Figure 4a shows the temperature (black solid) and dew point temperature (dashed) sounding idealized from the MISMO soundings. Thin lines either side of the temperature indicate standard deviations of temperature.

Variations of the humidity are relatively greater. Figure 4b shows relative humidity composites for 18 UTC soundings that were diagnosed with convection cells extending over horizontal scales clearly less than 100 km (blue) and with convection extending over horizontal scales clearly greater than 100 km. Though it is unclear whether these differences in relative humidity are statistically significant, large eddy simulation experiments exploring variation of the relative humidity are planned.

REFERENCES

Sobel, A. H., E. D. Maloney, G. Bellon, and D. M. Frierson, 2008: The role of surface heat fluxes in tropical intraseasonal oscillations. *Nature Geosci*, **1,** 653-657

Yoneyama, K., and Coauthors, 2008: Mismo Field Experiment in the Equatorial Indian Ocean. *Bull. Amer. Meteorol. Soc.*, **89,** 1889-1903, doi:10.1175/2008BAMS2519.1.

Yu, L., and R. Weller, 2007: Objectively Analyzed air-sea heat Fluxes for the global ice-free oceans (1981–2005). *Bull. Amer. Meteorol. Soc.*, **88,** 527-539